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Implementing a biofuel economy in the EU: Lessons from the SUSTOIL project and future perspectives for next generation biofuels

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ABSTRACT

The aim of this article is to illustrate main economic and environmental (GHG emission reductions) effects of implementing a biofuel economy and to discuss the potential of establishing advanced biofuels in the European Union. The study is based on the recently completed EU FP7 SUSTOIL research project. The main question addressed is the EU policy objective of achieving 20% GHG emission reductions using 20% of renewables by the year 2020. To contribute to the achievement of this policy we run and execute, through a Computable General Equilibrium model, a simulation experiment of implementing a bio-based economy using biorefineries in the production process. Main results suggest that: (a) biorefineries working from oil seeds and their by-products will lead to a large increase in the amount of this crop (grown particularly in Eastern Europe); (b) this increase will be accompanied by a decrease in sectoral GDP in several other areas; (c) oil and electricity prices will generally fall in across the EU with a particularly notable trend in Eastern Europe; and (d) a reduction in carbon emissions is achieved but this will be insufficient to meet the EU 20% target. This latter result would suggest to speed the technological process towards the use of next generation biofuels in the EU. Furthermore, these results advocate for a leading role expected to play by Eastern EU countries over the next years. The expected increase in the cultivation of energy crops could conflict with the availability of land for food crops. The potential for establishing next generation biofuels in the EU with adequate support policies would be essential for guaranteeing energy and food security in the long-run.

Contents

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1. Introduction

Since 1970s biofuels production started a new era of research and development initiatives in increasing bioenergy products from grown crops such as sugar cane, oil palm, switchgrass, maize, sugar beet, rapeseed to name a few. The success of these new energy crops has been substantial and mostly due to governments intervention through subsidising bio-energy crops production. Nothwidstanding the benefits to the environment in terms of CO_2 reductions, the growing debate of food vs first generation biofuels has posed doubts on the effectiveness of converting cereal into energy crops production.

If this assumption can be more realistic in developing countries where increasing population pushes demand higher through food crops production, less convincing this argument seems to be for the European continent. It is argued that European declining population growth would pose a serious downturn in food demand [1]. As a result, the vast and fertile European land would suffer productivity loss. The main question for Europe is to understand at what degree a bioenergy economy will affect current European climate change policy (e.g. GHG emission reductions) and at what extent the shifts in economic structure would alter the composition of GDP, land use for biofuels feedstock and energy prices.

To support the case of a European biofuel economy, new Member States will play a great role in producing biofuels over the immediate future: first, because of the productivity potential of Central and Eastern EU lands, and second the competitive advantage these regions would gain from infrastructure and transportation investments supported by the Community [2]. The latter would also justify current biofuels use within the EU predominantly for blending in transport at 5 or 10%. Furthermore, the Commission Directive 2009/28/EC on the 'Promotion of the use of energy from renewable sources' puts in place an exclusive framework for renewable energy production within Member States. In particular, the Directive sets reference values of energy from renewables computed from estimates of gross final demand by 2020. These reference values correspond to the achievement of the European Union '20-20-20' strategy adopted in March 2007 by the European Commission to further attain the goals of the Kyoto Protocol. The '20-20-20' policy establishes by the year 2020 to reach a target of 20% reduction of GHGs by using 20% renewables [3]. Given this ambitious scenario, Member States are required to set their shares of energy from renewables and create measures to promote the development of a competitive energy market which will ensure access to electricity network from renewables. The transport sector will play an important role to the development of biofuels use over the next years. Biofuels use in the transport sector would contribute to 14% of total market fuels (corresponding to about 43 million Tonnes of Oil Equivalent – Toe) and the share may increase from either current bioethanol production in Sweden or biodiesel production in Germany and other European Union countries or other feedstock such as ethanol from straw, rapeseed oil, palm oil and second generation biofuels mainly obtained from wood processes [4].

It is evident the need for Europe to underpin a biorefinery economy. This term suggests an economic system based on value added in green chemistry processes and materials and products such as ethanol, biodiesel, oils, acids, methanol and other proteins for use as fuels in food as well as other industries. Biorefinery uses organic waste material from agriculture and other primary sectors to transform it into biomass and renewable energy as well as promoting reductions in carbon emissions [5,6].

The biorefinery concept is currently widely used in a variety of research projects in the international community. This paper is based on the results of a recently completed EU Seventh Framework Programme (FP7) project titled 'SUSTOIL: Developing advanced biorefinery schemes for integration into existing oil production/transesterification plants' [54]. The project saw the participation of 23 institutions (universities and small and medium enterprises) across Europe. The rationale of the project was to develop advanced biorefinery schemes and integrate these into existing oil production plants to stimulate growth for the biofuels sector through the promotion of agricultural practices for non-food uses in countries with abundant land resources (i.e, Central and Eastern Europe).

The present study illustrates some of the results obtained from the combined work of two work packages of the SUSTOIL project. The study simulates, through the use of a Computable General Equilibrium model, the changes in the economic structure across EU countries and emission reductions that a biorefinery economy poses to attain the targets established by the 2007 European voluntary climate change policy. The work also provides a comprehensive discussion on the potential of implementing next generation biofuels in the EU providing explicit recommendations for further research.

The paper is structured as follows: Section 2 describes the modelling framework with particular reference to the theoretical analysis of the production process with biorefineries; Section 3 illustrates main data needed to construct a bio-based production structure as discussed in Sections 2; Section 4 shows relevant policy scenario analysis and results; Section 5 illustrates, in the light of the obtained results, a discussion on the potential role played by next generation biofuels in Europe and sheds some light on the perspectives for future research. Finally, Section 6 concludes.

2. Modelling framework

Computable General Equilibrium (CGE) models are a useful tool to analyse changes occurring in the economic as well as environmental process associated with national and international policies. In particular, CGE models are relevant to assess the effects linked to the implementation of various taxation policies, the degrees of openness to international trade, changes in production processes or redistributive policies [7–9]. More recently, such analyses have focussed on biofuel policies [10–12].

CGE models are based on Arrow and Debreu General Equilibrium (GE) theories where agents interact in competitive markets by setting up optimum quantities and prices satisfying all markets and agents' equilibrium conditions [13]. Interactions occur among productive sectors where each commodity is linked to input factors and commodities and among countries through international trade. CGE models and GE theories, through a converging process, reach equilibrium around a fixed point satisfying Walras' Law [14]. This process allows propagating effects to other sectors or countries of shocks originally occurred in a given sector or country due to the implementation of a particular new policy or set of policies.

Literature on modelling the economics of biorefineries (or biofuels more generally) is relatively recent. Most studies focus on projections and policy analysis in the short/medium term given a lack of time series data on biofuels [15]. Many existing models generally focus on extending food processes to include biofuels commodities [16,17]. The OECD study [17] considers the impact of biofuels production on land use in OECD countries. Main results suggest that assuming a Business as Usual (BAU) scenario (e.g. no changes occur in current production technology and international trade), US, Canada and EU would require additional crop land ranging from 30 to 70% to replace 10% biofuels in the transport sector. Further research focuses on the effects of the EU Biofuels Directive 2003/30/EC on agricultural markets [16]. Main findings

show a break (or even a reversed trend) in the decline of real world prices for agricultural commodities when energy crops are used for biofuels production. As a consequence, an increase in the price of land would occur in the EU (and a consequent decrease in international competitiveness) with negative effects on farmers and other economic agents. A mandatory subsidy for biofuels production (i.e., in the short run) would be advisable to help farmers to reach the goal of the Directive 2003/30/EC. Furthermore, improving competitiveness through R&D activities is a necessary step for the design of optimal sustainable development path and establishment of the biorefinery concept across the economy and environment.

The agricultural sector has received wide attention in biofuels studies. Recent works focussed on the implementation of the EU Biofuels Directive considering the agricultural sector and its full behavioural design [18,19]. Main results reveal that an increase in demand for biofuels would have positive impacts on arable land in existing EU Member States. Furthermore, domestic production would meet the requirements of ethanol and biodiesel use should high import tariffs be applied to world prices. As a consequence, EU farmers would see their income increase as well as employment opportunities. The focus on liquid biofuels in various OECD and non-OECD countries and their effects on agro-ecological zones has also received attention from current literature to incorporate biofuels into current consumption and production structures [19]. These studies suggest optimal substitutability of biofuels for petroleum products when crude oil prices increase. Also, demand for biofuels feedstock would mainly affect EU, Brazil and US; whereas land use impacts would be larger in Brazil.

Interesting reviews on interactions between economic, environmental and biofuels policies highlight the need of biofuels use and production in developing countries to help rural communities to reduce GHG emissions, creating new jobs and improving welfare conditions [20,21].

Early studies on the use of next generation biofuels analyse the effects of replacing biomass (switchgrass) to standard crude oil technologies in the US [22]. To include switchgrass in the Global Trade Analysis Project database, simulations on optimal input–output coefficients are conducted such that intermediate input coefficients correspond to 70% to those of cereals commodities. Replacing switchgrass to crude oil use in the oil industry would increase world price of cereals and decrease that of other types of crops and feedstock.

Recent generation of CGE models for bio-energy purposes are hybrid in nature. This means that these models integrate micro with macroeconomic aspects of a bio economy [11,23,24]. The specificity of these models is to integrate top down neoclassical growth model assumptions with bottom up methodologies to the modelling of primary energy input factors. Game theoretical behaviour features are also included to analyse optimal energy investment policies. Energy prices would be determined endogenously as well as technology change to include renewables. Main findings show that when the adoption of renewables is not mandatory free rider behaviours occur across industries and countries. Hybrid models are important tools for policy makers to implement optimal environmental policies [25]. In addition, these models can also contribute to investigate parameters estimates for substitution effects between capital and energy and the simultaneous adoption of renewable energy technologies.

2.1. *Theoretical modelling of the production structure with biorefineries*

The model extends earlier works on multi-country modelling [26,27] to consider a biobased economy. It is a static model for the ease of converging processes due to a large number of variables involved. In this section we describe the theoretical insight of the biorefinery production module. Model's notations are provided in Table A1 in Appendix. The production is a nested function as illustrated in Fig. 1.

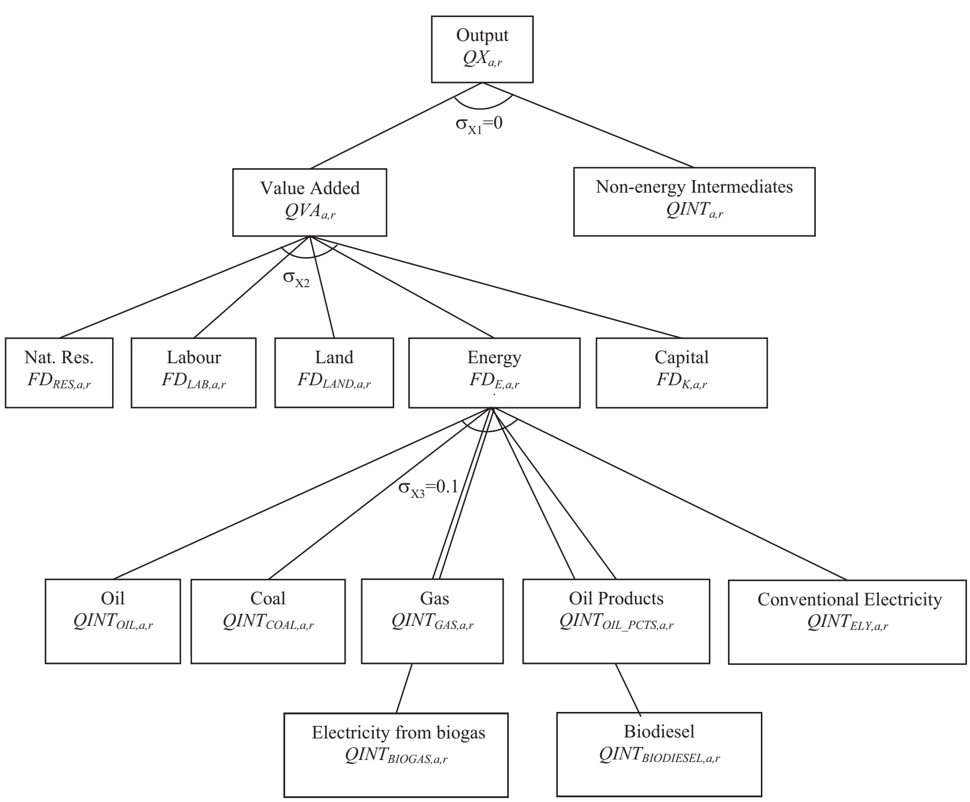

Fig. 1. Production structure with biorefineries.

In Fig. 1, total output $QX_{a,r}$ is obtained by employing a Leontief type technology (with zero substitution elasticity $\sigma_{x1}=0$) between non-energy intermediates ($QINT_{a,r}$) and a nested constant elasticity of substitution (CES) function for value added ($QVA_{a,r}$). Under a production structure perspective, different nesting levels allow for proper elasticity of substitution among all factors and accommodate the problem of no constant elasticity of substitution when using multiple factors to production [28].

The use of a Leontief technology is economically justified when its technical coefficients derive from accounting data. In this model, data derive from Social Accounting Matrices.[1] As such, the constancy of input–output coefficients is the equivalent to assume optimising behaviours of the production function and profit maximisation [29]. $QINT_{a,r}$ is obtained as

$$QINT_{a,r} = \sum_{a} io_{a,r} \times QX_{a,r} \tag{1}$$

in Eq. (1), the demand for non-energy intermediate inputs is the sum of input–output coefficients ($io_{a,r}$) across sectors, multiplied by activity output ($QX_{a,r}$). At the second nest of the production function the value added ($QVA_{a,r}$) in Eq. (2) is obtained by a nested CES function that allocates demand for land ($FD_{LAND,a,r}$), demand for labour ($FD_{LAB,a,r}$), demand for natural resources ($FD_{RES,a,r}$), demand for capital ($FD_{K,a,r}$) and demand for an energy bundle ($FD_{E,a,r}$). These belong to the set f in total demand factors ($FD_{f,a,r}$).

$$QVA_{a,r} = A_{2a,r}\begin{bmatrix} \alpha_{2LAB,a,r}FD_{LAB,a,r}^{\rho_{2a,r}} + \alpha_{2RES,a,r}FD_{RES,a,r}^{\rho_{2a,r}} + \alpha_{2LAND,a,r}FD_{LAND,a,r}^{\rho_{2a,r}} + \\ + \alpha_{2K,a,r}FD_{K,a,r}^{\rho_{2a,r}} + \alpha_{2E,a,r}FD_{E,a,r}^{\rho_{2a,r}} \end{bmatrix}^{1/\rho_{2a,r}} \tag{2}$$

where $A_{2a,r}$ is the efficiency parameter and $\alpha_{2LAB,a,r}$, $\alpha_{2RES,a,r}$, $\alpha_{2LAND,a,r}$, $\alpha_{2K,a,r}$ and $\alpha_{2E,a,r}$ are subsets of $\alpha_{2f,a,r}$. These latter parameters represent the share of the respective factor demand in value added whereas $\rho_{2,a,r}$ refers to calibrated values of the elasticity of substitution across input factors.[2]

The use of the CES function (in production as well as in other modules, i.e trade) is defined "for positive levels of inputs, it is continuous, differentiable, monotonic and strictly quasi-concave. Moreover, this special form exhibits constant returns to scale" [32, p. 3] which is a common adoption in CGE models under the assumption of competitive markets.

First Order Conditions (FOCs) satisfy interior solutions such that the ratio of marginal productivity of inputs and the inputs cost ratio are equal. We determine conditional demands for each input factor. Conditional demands have the properties of being "non-decreasing and homogenous of degree one with respect to the level of production, homogenous of degree zero with respect to input prices, non-increasing with respect to the own-price and non-decreasing with respect to the output price" [32, p. 4].

Furthermore, due to the constant returns to scale property of the CES function we simplify conditional demand equations introducing unit cost functions. Unit cost functions do not vary with output level. As a consequence, total cost functions are homogenous of degree one with respect to the output level. Also, unit cost functions allow us to express conditional demands as function of marginal costs. We determine demand equations for each model's structure and use calibration to obtain initial values of main parameters. Finally, we run common maximisation analysis according to the works of Global Trade Analysis Project (GTAP) modellers [55,33,34].

The tangency condition in the value added nest satisfies the neoclassical requirement that the price of factor demands ($WF_{f,r}$) should be equal to the value of the marginal product (the FOCs in Eq. (2)) such that:

$$WF_{f,r} = PVA_{a,r}A_{2a,r}\left[\sum_{f} FD_{f,a,r}^{\rho_{2a,r}}\right] \times \alpha_{2f,a,r}FD_{f,a,r}^{\rho_{2a,r}-1} \tag{3}$$

where $PVA_{a,r}$ is the value added price. The respective factor demand equations result as follows:

$$FD_{RES,a,r} = \left(\frac{QVA_{a,r}}{A_{2a,r}}\right)WF_{RES,r}^{\rho_{2a,r}} \times \left[A_{2a,r}WF_{RES,r}\right]^{\rho_{2a,r}/(1-\rho_{2a,r})} \tag{4}$$

$$FD_{LAND,a,r} = \left(\frac{QVA_{a,r}}{A_{2a,r}}\right)WF_{LAND,r}^{\rho_{2a,r}} \times \left[A_{2a,r}WF_{LAND,r}\right]^{\rho_{2a,r}/(1-\rho_{2a,r})} \tag{5}$$

$$FD_{LAB,a,r} = \left(\frac{QVA_{a,r}}{A_{2a,r}}\right)WF_{LAB,r}^{\rho_{2a,r}} \times \left[A_{2a,r}WF_{LAB,\ r}\right]^{\rho_{2a,r}/(1-\rho_{2a,r})} \tag{6}$$

$$FD_{K,a,r} = \left(\frac{QVA_{a,r}}{A_{2a,r}}\right)WF_{K,r}^{\rho_{2a,r}} \times \left[A_{2a,r}WF_{K,r}\right]^{\rho_{2a,r}/(1-\rho_{2a,r})} \tag{7}$$

where $WF_{RES,r}$, $WF_{LAND,r}$, $WF_{LAB,r}$, $WF_{K,r}$ are all subsets of $WF_{f,r}$.

On the third nest of the production function in Fig. 1, the energy bundle ($FD_{E,a,r}$) is obtained by combining energy and bio-energy commodities:

$$FD_{E,a,r} = A_{3a,r}\begin{bmatrix} \alpha_{3OIL,a,r}QINT_{OIL,a,r}^{\rho_{3a,r}} + \alpha_{3GAS,a,r}QINT_{GAS,a,r}^{\rho_{3a,r}} + \alpha_{3COAL,a,r}QINT_{COAL,a,r}^{\rho_{3a,r}} + \\ + \alpha_{3OIL\_PCTS,a,r}QINT_{OIL\_PCTS,a,r}^{\rho_{3a,r}} + \alpha_{3ELY,a,r}QINT_{ELY,a,r}^{\rho_{3a,r}} + \\ + \alpha_{3BIOGAS,a,r}QINT_{BIOGAS,a,r}^{\rho_{3a,r}} + \alpha_{3BIODIESEL,a,r}QINT_{BIODIESEL,a,r}^{\rho_{3a,r}} \end{bmatrix}^{1/\rho_{3a,r}} \tag{8}$$

where $\alpha_{3OIL,a,r}$, $\alpha_{3GAS,a,r}$, $\alpha_{3COAL,a,r}$, $\alpha_{3OIL\_PCTS,a,r}$, $\alpha_{3ELY,a,r}$, $\alpha_{3BIOGAS,a,r}$, $\alpha_{3BIODIESEL,a,r}$ are all subsets of $\alpha_{3f,a,r}$. The tangency condition of the energy composite nest is

$$WF_{f,r} = PQINT_{a,r}A_{3a,r} \times \left[\sum_{f} \alpha_{3a,r}QINT_{a,r}^{\rho_{3a,r}}\right] \times \alpha_{3a,r}QINT_{a,r}^{\rho_{3a,r}-1} \tag{9}$$

where $PQINT_{a,r}$ is the price of intermediate energy and bio-energy commodities.

The price system of the production block is mainly given by two equations. The first one (Eq. (10)), defines the composite price of output ($PX_{a,r}$) in terms of commodity prices ($PXC_{a,r}$); the second one (Eq. (11)), defines the value added price ($PVA_{a,r}$) in terms of activity price ($PX_{a,r}$) minus intermediate inputs price ($\sum_a PQ_{a,r}\ io_{a,r}$). Furthermore, the activity price ($PX_{a,r}$) is considered net of: (a) production taxes ($tx_{a,r}$) and factor taxes ($tfu_{f,a,r}$) applied on the volume of factor demands ($WF_{f,r}\ FD_{f,a,r}$) divided by the amount of total production ($QX_{a,r}PX_{a,r}$); and (b) total emission taxes ($\sum_{type} Emiss_{type,a,r}$) multiplied by their respective emission rates ($EmRate_{r,type,a}$) divided by the amount of total production ($QX_{a,r}PX_{a,r}$).

$$PX_{a,r} = PXC_{a,r} \tag{10}$$

$$PVA_{a,r} = PX_{a,r} \times \left[1-(tx_{a,r}) - \left(\frac{\sum_{f} tfu_{f,a,r}WF_{f,r}FD_{f,a,r}}{QX_{a,r}PX_{a,r}}\right) - \left(\frac{\sum_{type} Emiss_{type,a,r}EmRate_{r,type,a}}{QX_{a,r}PX_{a,r}}\right)\right] + \sum_{a} PQ_{a,r}io_{a,r} \tag{11}$$

3. Data

Country and multi-country level CGE studies are often based on the use on Social Accounting Matrices (SAMs) containing extended information on the relationships across all economic accounts. A SAM is a square matrix in which each account is a row and column entry. Rows record incomes to given economic sectors/agents while columns consider expenditures by specific sectors or economic agents. The system is based on the fundamental identity of national income and, as a consequence, total rows and columns must always balance.

[1] See also Section 3.

[2] In calibration analysis, CGE modellers commonly use the standard Arrow, Chenery, Minhas, and Solow (ACMS) CES production function in which the elasticity of substitution corresponds to set $\sigma=1/(1-\rho)$ [30,31].

Table 1
Model's sectoral description.

Sectors	Description
Existing sectors	
oth_agr	Agriculture and forestry
osd	Oilseeds
en_int_ind	Other energy intensity industries
oth_ind	Other industries
gas	Gas
coa	Coal
oil	Oil
oil_pcts	Petroleum oil products
transp	Transport
ely	Electricity
Bio sectors	
BIODIESEL	Biodiesel[a]
BIOGAS	Biogas[a]

[a] Biodiesel and biogas are not considered as traded commodities.

As such, a SAM provides a conceptual and behavioural framework where economic components are linked to each other incorporating real world data on intersectoral economic flows which are essential to the calibration and development of empirical CGE modelling [35]. In this study we use SAMs developed by GTAP database v.6 and behavioural relationships across accounts are adapted by current literature [33,34]. Original SAMs in the GTAP database are also extended to consider CO_2, SO_2, and NO_x emissions and the biorefinery module.[3]

Emissions are added in the SAM by column entry and take into account only the production part of the economic system. These can be considered as by-products of production activities deriving from fossil fuel use (energy) such as coal, oil, and natural gas. Energy input data are based on the OECD-IEA Energy Balance and Energy Statistics Tables for the year 2001[4]. World energy prices are taken from BP statistics [56]. SO_2 and NO_x emissions factors have been obtained by the RAINS model of the International Institute of Applied Science IIASA [36]. CO_2 equivalent emission factors have been gathered from an extensive and detailed work by the Department of Environment, Food and Rural Affairs, UK [57].

3.1. Model's geographical and sectoral structure

Table 1 shows the sectoral composition of the model. This is given by existing GDP activities and bio-economic sectors (biodiesel and biogas). In terms of geographical structure, we consider four EU country groups such as: NorthEU (Denmark, Finland, Ireland, Sweden, UK), SouthEU (Greece, Italy, Portugal, Spain), WestEU (Austria, Belgium, France, Germany, Luxemburg, The Netherlands) and EastEU$_{new12}$ (Bulgaria, Czeck Republic, Hungary, Poland, Romania, Slovak, Estonia, Latvia, Lithuania, Malta, Slovenia, Cyprus) which refers to new EU Member States[5].

3.2. Data for the biorefinery module

The model considers two optimal biorefinery schemes such as biogas and biodiesel[6]. Tables 2 and 3 refer to input and output data obtained by an optimisation analysis [37]. Values are based on the assumption of a small plant producing 7.8 kt/yr of biodiesel working full time (24 h a day) for 330 days/yr.

Table 2
Input and output data for biodiesel refinery.
Source: [37].

Input and output	Value	Unit
Input		
Labour	6233.04	Man hours/yr
Maintenance	25608.79	Euros/yr
Insurance + capital charges	48656.70	Euros/yr
Other utilities	26684.36	Euros/yr
Heat	13020480	kWh/yr
Electricity	3458.66	kWh/yr
Cooling	2395008	kWh/yr
Raw M. (Methanol)	1713.10	Tonnes/yr
Raw M. (Rapeseed)	24750	Tonnes/yr
Raw M. (Potassium hydroxide)	118.80	Tonnes/yr
Raw M. (Hydrocloric acid)	158.40	Tonnes/yr
Output		
Biodiesel	7875.65	Tonnes/yr
Crude glycerol	686.51	Tonnes/yr
Rapeseed meal	14850	Tonnes/yr

Table 3
Input and output data for biogas refinery.
Source: [37].

Input and output	Value	Unit
Input		
Labour	4926.56	Man hours/yr
Maintenance	162314.2	Euros/yr
Insurance + capital charges	40578.5	Euros/yr
Other utilities	76084.8	Euros/yr
Water	15269.76	Tonnes/yr
Raw M. (Rapeseed straw)	10692	Tonnes/yr
Output		
Bio-electricity	24624	1000 kWh/yr
Heat	28963	1000 kWh/yr
Fertiliser	1575	1000 kWh/yr

For the biodiesel refinery, labour values are obtained from current literature [38]. This estimates that 15 men working full time (8 h a day) are required for a plant producing 50 kt/yr of biodiesel. We rescaled this value according to the requirements of our small plant and obtained corresponding labour demand (6233.04 man h/yr). The incidence of maintenance, insurance and other capital costs are also obtained from current studies [38] and re-scaled to fit our plant size. These costs account for 1.57% and 1.64% of total fixed costs (1,626,988 Euros/yr) [37].

For the biogas refinery (Table 3), original labour values from the optimisation study [37] were expressed in the range of 0.0005–0.0035 man/kWh. We considered an average value of 0.002 man/kWh for our modelling purposes. The biogas refinery uses rapeseed straw as main raw material in its production process. This scheme would also appear to be water intensive for using cooling systems for biogas engines. Finally, the biogas refinery produces around 25 million kWh/yr of electricity and just about 29 million kWh/yr of green heating.

Some other useful information for the construction of the biorefinery industry is shown in Table 4 in terms of country labour cost structure. Furthermore, the biogas refinery considers the following input factor prices across countries: 0.145 Euros/kWh (electricity), 0.03 Euros/kWh (heating), and 98.1 Euros/kWh (fertiliser) [37].

Finally, data on conversion and emission factors from fossil fuel use take into account the following values across sectors: 3.12 t of

[3] See Section 3.2.
[4] The choice of the year 2001 is consistent with GTAP database v.6.
[5] Croatia is not considered in our model.
[6] The choice of these two schemes is not casual. Biogas and biodiesel schemes have been selected out of five schemes which resulted to be optimal in terms of net profits and CO_2 emission reductions. The optimisation study has been conducted by the University of Manchester which was one of the SUSTOIL partners [37].

Table 4
Labour prices and labour cost structure for both biodiesel and biogas refineries. *Source*: [40]. Average labour prices in renewable electricity from biodiesel and biogas refineries are considered as well as those in conventional electricity sector. Data for Belgium and Greece refer to the year 2003. Data For Italy, The Netherlands, and Ireland refer to the years 2004, 2005 and 2006, respectively.

	Avg/h, in Euros	Employment Tx, % of lab. costs	Wage gross, % of lab. costs	Income Tx, % of lab. costs
NorthEU	37.92	21.26	78.74	11.95
SouthEU	26.14	23.98	76.02	5.68
WestEU	28.87	19.15	47.52	6.06
$EastEU_{new12}$	9.75	23.67	76.33	9.44

CO_2 per Toe from oil (2.96 in the transport sector); 3.66 t of CO_2 per Toe from coal and 2.27 t of CO_2 per Toe from natural gas [39].

3.3. Elasticity values

Determining elasticity values is essential to model behavioural parameters in a CGE model. These define the degree of responsiveness of agents to substituting factors in the production processes, or substituting commodities for consumption purposes or substituting goods between home and foreign markets.

Generally, elasticities are measured as the ratio between the proportionate change of the quantity of two inputs and their proportionate change in relative prices.

We assume little substitution effects ($\sigma_{X3}=0.1$) between biorefinery and conventional technology (Fig. 1). This would justify either the moderate use of biofuels blending at 5% or 10% [41] in Europe or the adoption of complementarity hypotheses between biorefineries and traditional fossil fuels use in current literature of biofuels modelling [19,16].

4. Policy experiment and main results

The main question addressed in this study is for a biobased economy the achievement of the EU energy policy package's goal [3]. To attain this policy, we run and execute a simulation experiment which consists of implementing a bio-refinery based economy in the production process. The following description illustrates main model's results.

4.1. Percentage change in sectoral GDP

Major changes occur in new Member States across almost all economic sectors (Table 5). There exists a high change in the oil seed sector of 627.8%. This particular high value is due to the increasing production of oilseeds to satisfy bio-refineries requirements in these countries. As expected, other agricultural sectors undergo negative GDP changes. Furthermore, increased EU subsidies in the agricultural as well as other economic sectors in new Member States play their role in determining shocks in the oil seed industry. Positive impacts are also evident in the gas and electricity industries as well as the oil seed sector in western and northern EU countries, in the electricity sector (across all countries) and coal industry (particularly in SouthEU).

4.2. Welfare change

New Member States suffer major negative welfare impacts in the region of 8 billion Euros (Table 6). We believe that this result could not be attributable entirely to the implementation of a biorefinery based economy; it rather would be the combining effect of the overall restructuring of the economy after the accession to the EU that these countries are still experiencing.

Table 5
Percentage change in existing sectoral GDP.

	NorthEU	SouthEU	WestEU	$EastEU_{new12}$
oth_agr	−12.75	−4.76	−2.87	−43.84
osd	203.90	−22.53	223.10	627.8
en_int_ind	−11.47	−13.48	−4.68	−41.65
oth_ind	−7.53	−6.88	1.73	−37.82
gas	5.73	−30.35	−11.00	28.95
coa	−8.81	7.95	−5.21	−1.87
oil	−21.83	−23.78	−13.42	−61.28
oil_pcts	−21.21	−23.94	−12.41	−63.99
transp	−12.16	−13.74	−2.10	−51.25
ely	6.28	12.18	10.24	42.28

Table 6
Welfare in million Euros.

	NorthEU	SouthEU	WestEU	$EastEU_{new12}$
Welfare	858.66	1655.09	4949.54	−8149.76

Table 7
Percentage change in land use, and oil and electricity prices.

Sectors	NorthEU	SouthEU	WestEU	$EastEU_{new12}$
osd	181.33	−20.16	187.61	399.23
Total land	13	−1.96	14.38	96.31
Prices				
Oil	−15.48	−14.57	−14.41	−24.27
Electricity	−2.25	−3.13	0.04	−8.47

Table 8
Percentage change in emissions.

	NorthEU	SouthEU	WestEU	$EastEU_{new12}$
CO_2 equivalent	−12.64	−14.82	−8.82	2.70
NO_x	−11.20	−11.92	−8.17	6.18
SO_2	−15.33	−13.82	−9.67	−3.22

4.3. Percentage change in land use, and oil and electricity prices

Two aspects are relevant to consider for land use in a biorefinery economy (Table 7). The first one is how much land use changes because of an increased use of oil seeds. Major changes (as it was expected given the high GDP change in the oil seed sector) occur in new Member States. In western and northern EU countries changes are rather small compared to those in new Member States but still large. However, these changes should be compared to those ones appearing in total land use. There exists a high impact of total land use change in new Member countries (96%). We argue that this could be the result of a higher demand of land for biofuels feedstock (i.e. oilseed) and production in Eastern and Central European countries [42].

Table 7 also shows percentage changes in oil and electricity prices. In particular, oil prices decrease in all countries and major changes occur in new Member States in the figure of 25%. Likewise, electricity prices also decrease with a minor impact on the economy. Both trends in oil and electricity prices would indicate a positive effect of biorefinery industries in the EU economy.

4.4. Percentage change in emissions

The existence of a biorefinery economy would help reducing emissions in almost all countries (Table 8). New Member States would still suffer from increases in CO_2 and NO_x emissions. It is reasonable to argue that implementing a biorefinery in the EU would not contribute to achieve the 20% reduction as established in the '20-20-20' policy package. Nonetheless, the '20-20-20' policy establishes that the 20% reduction should be achieved by the contribution of all renewables (i.e. including wind and solar power energy sources). Our results suggest that, on average, an 8% reduction of CO_2 emissions occurs across countries.

5. Perspectives for next generation biofuels in the EU: a discussion for further research

Biofuels are already the dominant renewable energy source in Europe and their production is likely to increase greatly in the coming years. Controversies still remain for fuels vs food issues peaked with the economic downturn in 2008. Continuous and large scale biorefinery production from edible oils bears the risk of land-use change due to land and forest conversion to first generation biofuel crops. Land use change would not only have repercussions in the EU but its effects is likely to imply knock-on impacts to occur in other parts of the world (due to the propagation of effects through trade relations) where more land will be needed to convert into farmland, which may further aggravate the GHG emissions problem [4].

Furthermore, expanding arable crops would also have a direct impact on other environmental issues such as water usage (for irrigating crops and evapotranspiration), eutrophication (due to fertilizers use into natural waters) and soil erosion and deforestation [43]. Recent UNEP studies [44,45] emphasise the risk for deforestation in particular in developing countries. In Indonesia for example the total rainforest would be reduced by 29% compared to 2005 levels if current harvesting continues to take place. In Europe, deforestation and soil erosion is particularly relevant in Mediterranean regions and few Eastern new Member States. On the other hand, several afforestation projects are currently being developed under the EU LIFE program and the risks could be lessened with an adequate choice of energy crops management based on current and future technology developments in agriculture and forestry sector. Biofuels from wastewater, crop or forestry residues offer an undoubted number of environmental and economic advantages.

Jatropha or switchgrass for example are perpetual crops that can guarantee a biological harvesting of more than thirty years; they can adapt to grow at various environmental conditions and obtain biodiesel yields productivity for a long time span [46].

Advances in new technologies provide the possibility to produce cellulosic biofuels from inedible biomass feedstock. This ensures substitutability with conventional fossil fuels and contributes to a larger amount of energy supply with positive effects, in particular, on job creation and the economy of marginal areas in the EU. Simulation analysis studies [47] emphasise the role of forest residues and marginal lands on the expected increase of biodiesel demand. At a global level, simulation analysis considers a series of scenarios which range from less to more optimistic views of forest residues and biomass availability (i.e. 10 to 16 or 43 Exajoule (EJ) [47]). A recent study conducted at European Union scale [48] estimated that under an optimistic scenario a surplus of 129–592 Mha of marginal land would have an impact of potential biodiesel production between 100 EJ and 303 EJ. In particular, new European Union and candidate countries could serve as European supplier of next generation biofuels. This result would also validate the role played by these countries in our model.

The issue of marginal lands for next generation biofuels is not without limitations. Biomass production requires a large amount of lignocellulosic feedstock and with current technology the integration between food and energy systems appears to be still an expensive solution [49]. Certainly, policy uncertainties and current economic and financial crisis have slowed down the rate at which technology develops from experimentation to commercialisation.

Investments to sustain R&D in advanced biofuels would play a great role to reach the EU renewable energy package goals. Funding opportunities within the Community (e.g. through the FP7) have assigned $2.5 billion for future generation biofuels research. Several projects already funded under the FP7 range from research cooperation within (i.e. BIOREGIONS, Agri for Energy II, AFO) and outside the EU (e.g. CANEBIOFUEL, a cooperation between Sweden and Brazil on costs effectiveness for lignocellulosic ethanol) [58].

Numerous initiatives should also address the cultivation of micro-algae. Outside the EU, Malaysia is an excellent example of governmental support to encourage private R&D in algae biodiesel. In Europe, two major projects in France to convert algae to fuels (including marine fuels applications), electricity and industrial chemicals are under development to contribute to reach the EU and French energy targets by 2020 [59]. Other EU projects under the EU FP7 Programme have been funded to stimulate research in wastewater treatments and promote a 'biorefinery based on algae' concept [60].

If technology progress proves to be effective the implementation of lignocellulosic and algae biodiesel is likely to dominate future EU land use change including protection for biodiversity and effective management of carbon sequestration. Effective and balanced management is also required for sustainable harvesting of perennial lignocellulosic crops and crop yields improvements. Guaranteeing efficient solar radiation has, in fact, implications for carbon stocks and soil organic composition offering yield stability in the short as well as in the long term (30 years).

Support regulation and monitoring are also required to accurately estimate future land availability to meet EU targets for biofuels demand. It should be taken into account that our current model as well as other studies are biased towards actual assumptions on crops and land availability. It is likely that wood and algae-biodiesel which have good adaptation to grow on marginal land or water will also find optimal use in terms of enabling positive carbon balances over time and include these into a further research for dynamic applications. Furthermore, the development of biofuels production can be enhanced with the intensification of agricultural management practises on arable land for food and energy crops [50]. These intensification management practises will have beneficial effects on GHG savings, improved soil productivity and biodiversity protection [51].

To further address uncertainties about future breakthroughs that would make future generation biofuels a truly viable option, policymakers need to consider carefully which goals to pursue in support of different biofuels. The US, for example, is currently adopting a blending mandate which requires the use of lignocellulosic feedstock up to 60.6 billion/l/yr to ensure a reduction of 100 million tonnes of CO_2/yr by 2022 [52]. The EU has currently increased the share of renewables in transportation to 10% by 2020 but does not set a blending mandate for next generation biodiesel. Directive 2009/28/EC defines general sustainability standards to save GHG emissions from biofuels.

Further research should be addressed to emphasise simulations analysis and incorporate specific regulations for various types of biofuels (i.e biodiesel, ethanol, and methanol) and technology solutions [53]. This would also be the premise of further empirical

investigation for substitution effects among biofuel commodities, feedstock and different technology embedded in production processes.

6. Conclusions

In this study we analysed the effects of implementing a biorefinery economy in the EU across a number of economic and environmental (GHG emission reductions) variables. Through the use of a CGE model we studied how the economic structure of European countries would change to address the Community goal of reducing 20% GHG emissions by the year 2020 employing a European biorefinery economy [3].

Main results suggest that biorefineries working from oil seeds and their by-products will lead to a large increase in the amount of this crop grown in particular in new Member States. This is counterbalanced by decreases in sectoral GDP in several other areas across countries. Furthermore, oil and electricity prices show a general fall across the EU with a particularly notable trend in Eastern Europe.

Finally, in terms of GHG emissions (in particular CO_2) a decrease is evident but not sufficient to meet the European target of 20%. Notwithstanding, biorefineries contribute largely to decrease emissions with an 8% average reduction across the EU. This is a satisfying result considering that the 20% target set in Directive 2003/30/EC should be achieved by all renewables (i.e. including wind and solar power energy sources). The leading role expected to play by Eastern EU countries over the next years addresses the question of implementing a clear designation policy, at central or national level, to guarantee energy and food security in the long-run.

Technological progress is an essential factor for the efficient management of the EU energy policy package. Uncertainties due to current financial crisis have slowed down the rate at which technology developments for future generation biofuels progresses. A viable option given the current state of the economy is to consider which goals policy makers want to pursue in support of different biofuels (i.e biodiesel, ethanol, and methanol). Further empirical investigation could answer this question through the analysis of substitution effects across biofuels inputs, dynamics of land availability and investments in R&D for biorefineries.

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Appendix A

See Appendix Table A.1.

Table A.1
Notations used in the theoretical model.

Notations	Description
a	Set of activities or sector
c	Set of commodities
d	Set of domestic commodities
m	Set of imported commodities
r	Set of regions
w	Set of trade partner region
f	Set of input factors
A	Set of efficiency parameter in production function
σ	Set of elasticity of substitution in production function
ρ	Set of calibrated values of elasticity of substitution in production function
$QX_{a,r}$	Total output
$QINT_{a,r}$	Non-energy intermediates
$QINT_{OIL,a,r}$	Oil intermediates
$QINT_{GAS,a,r}$	Gas intermediates
$QINT_{COAL,a,r}$	Coal intermediates
$QINT_{OIL\_PCTS,a,r}$	Oil products intermediates
$QINT_{ELY,a,r}$	Electricity intermediates
$QINT_{BIOGAS,a,r}$	Biogas intermediates
$QINT_{BIODIESEL,a,r}$	Biodiesel intermediates
$QVA_{a,r}$	Value added
$io_{a,r}$	Input–output coefficients
$QX_{a,r}$	Activity outputs
$FD_{f,a,r}$	Total factor demand
$FD_{LAND,a,r}$	Demand for land
$FD_{LAB,a,r}$	Demand for labour
$FD_{RES,a,r}$	Demand for natural resources
$FD_{K,a,r}$	Demand for capital
$FD_{E,a,r}$	Demand for energy bundle
$WF_{f,r}$	Factor demand price
$WF_{RES,r}$	Natural resource price
$WF_{LAND,r}$	Land price
$WF_{LAB,r}$	Labour price
$WF_{K,r}$	Capital price
$PVA_{a,r}$	Price of value added
$PQINT_{a,r}$	Price of intermediates
$PX_{a,r}$	Composite price of output
$PXC_{a,r}$	Commodity price
$tx_{a,r}$	Production tax
$tfu_{a,r}$	Factor tax
$Emiss_{type,r,a}$	Emission type
$EmRate_{r,type,a}$	Emission rate

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